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Types and Formation Mechanism of Typical Submarine Geological Hazards of Coastal Islands in China

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Single beam, side-scan sonar, sub-bottom profiler and other survey equipments are adopted for investigation of submarine geological hazards in 15 coastal islands of China, namely, Zhangzi Is., Changxing Is., Caofeidian Is., Lingshan Is., Tuoji Is., Beichangshan Is., Chongming Is., Liuheng Is., Waidiaoshan Is., Xiushan Is., Zhujiadian Is., Jintang Is., Dongshan Is., Donghai Is. and Weizhou Is.. Data analysis and researches show that typical submarine geological hazards of coastal islands in China mainly cover 10 types: submarine landslide, submarine slope, seabed erosion, tidal ridges, moving sandwaves, shallow gas, wedge-shaped deposits, buried oblique layer, seabed siltation and coral reef degradation, and can be classified into gravity - hydrodynamic force cause, hydrodynamic force cause, pneumatic force cause, biological activity cause and human activity cause, among which hydrodynamic force cause accounts for the largest proportion and seabed erosion is the most developed, with the proportion of geological hazard attributed to human activity increasing rapidly.

[Keywords: Coastal island; Hazard type; Submarine geological hazards]

Introduction

As the base and fulcrum of exploiting the ocean, coastal island is deemed as the second marine economic zone, and shares a special and important position in terms of territory demarcation and national defence security and is of great significance to constructing a marine economic power. For example, some large ports and bases make full use of the natural advantages of coastal island. Submarine geological hazard of coastal island refers to geological phenomenon and processes distributed in nearshore area around island, which cause direct loss to life and property of people living in coastal island, damage the geological, ecological environment and geomorphologic landscape, and impose negative influence and indirect loss on economic and social development of coastal island. Along with the rapid development of coastal economy and increasing spatial resource shortage leads to frequent geological hazards, thus seriously impacting the environment of coastal island. Besides, rescue is rather difficult due to its relative isolation^{1,2}, so geological hazard of coastal island raises more and more attention.

There are 10,312 coastal islands (including Hong Kong, Macau and Taiwan) in China, mainly in form

of bedrock island, followed by heaped-up island, coral island and volcanic island. With a total shoreline of 16,775 km and land area of 77,224 km², coastal islands spans 38 latitudes from south to north³. Statistical results from investigation on geological hazard of coastal islands in China conducted during 2011 and 2015 indicates that it falls into two categories: island-land and submarine. The former mainly occurs in 14 hazard types: landslide, coastal erosion, saltwater intrusion, wetland degradation, water & soil loss, beach face washout, land subsidence, eolian disaster, fault, coastal deposit, sandbeach argillization, sand liquefaction, soft soil foundation and earthquake⁴, while the latter mainly covers 10 types: submarine landslide, submarine slope, seabed erosion, tidal ridges, sandwaves, shallow gas, wedge-shaped deposits, buried oblique layer, seabed siltation and coral reef degradation, and is widely developed on nearshore seabed of coastal island, which imposes serious impact on island environment and nearshore projects. Despite of relatively mature research in geological hazard of land area, a few researches have been done in submarine geological hazard of coastal island, so relevant investigations and researches need to be strengthened.

Materials and Methods

Study area

According to different latitude zones and position of coastal islands, 15 various typical coastal islands along the coastal line of China from north to south are selected (Figure 1; Table 1) Among them, Caofeidian Is. and Chongming Is. belong to alluvial island, Donghai Is. and Weizhou Is. belong to volcanic island, while the rest refers to bedrock island.

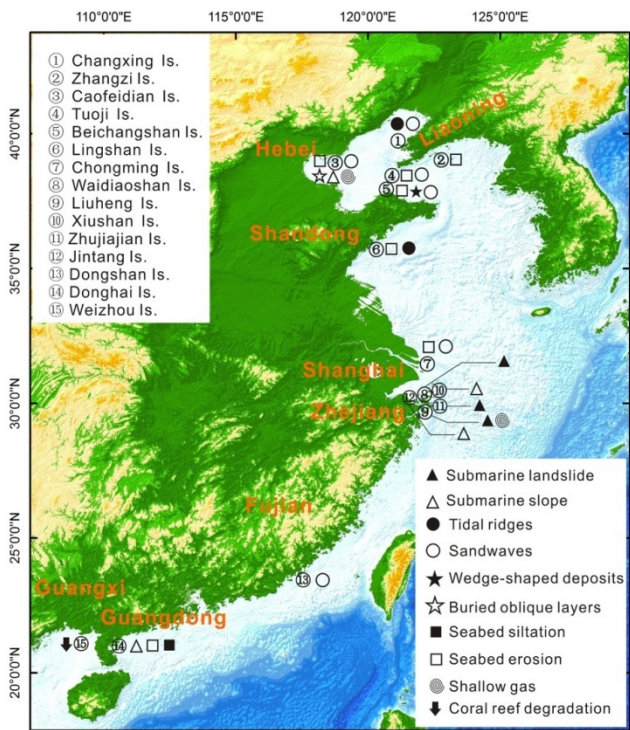


Fig.1 — Map of the position and hazard type of 15 typical coastal islands

Methods

(1) Topographic bathymetry survey

Hydrotrac digital single-frequency echosounder of ODOM Hydrographic Systems was adopted for bathymetry, equipped with TSS motion sensor to improve the precision. Meanwhile, DGPS positioning error caused by ship movement was corrected to enhance the position accuracy of depth point.

(2) Submarine topography detection

4200 MP dual-frequency sonar system of EdgeTech, featured by slant distance correction, target finding and real-time mosaicing was adopted for investigation, and SonarWiz.MAP software of Chesapeake was applied for data acquisition, with sonar range setting of 75 m for side scanning.

(3) Sub-bottom profiler survey

Sub-bottom survey owns a superiority to other investigation methods and approaches in Quaternary stratigraphic sequence, engineering geological unit delineation and submarine geological hazard identification. C-Boom sub-bottom profiler manufactured by C-Products is adopted for investigation, which features a penetration depth of 80 m, resolution higher than 0.3 m, favorable data quality, high SNR, clear boundary line between strata layers, continuous and identifiable phase.

Geo-Hazards classification

There are not so many research and classification with respect to geological hazard of coastal island. Carpenter (1980)⁵ classified geological hazard in outer shelf of the Atlantic into disaster factor and geological obstacle factor. Brynant (1983)⁶ classified

Table1 — The basic situation of the fifteen coastal islands

No.	Name	Area	Types	Province
1	Changxing Is.	The Bohai Sea	Bedrock Island	Liao Ning
2	Zhangzi Is.	The Yellow Sea	Bedrock Island	Liao Ning
3	Caofeidian Is.	The Bohai Sea	Alluvial Island	He Bei
4	Tuoji Is.	The Bohai Sea	Bedrock Island	Shan Dong
5	Beichangshan Is.	The Bohai Sea	Bedrock Island	Shan Dong
6	Lingshan Is.	The Yellow Sea	Bedrock Island	Shan Dong
7	Chongming Is.	The East China Sea	Alluvial Island	Shang Hai
8	Waidiaoshan Is.	The East China Sea	Bedrock Island	Zhe Jiang
9	Liuheng Is.	The East China Sea	Bedrock Island	Zhe Jiang
10	Xiushan Is.	The East China Sea	Bedrock Island	Zhe Jiang
11	Zhujiajian Is.	The East China Sea	Bedrock Island	Zhe Jiang
12	Jintang Is.	The East China Sea	Bedrock Island	Zhe Jiang
13	Dongshan Is.	The East China Sea	Bedrock Island	Fu Jian
14	Donghai Is.	The South China Sea	Volcanic Island	Guang Dong
15	Weizhou Is.	The South China Sea	Volcanic Island	Guang Xi

it into fault, shallow gas, carrier gas sediment, burial ancient river course, sandwaves, diapiric fold and submarine groove based on concrete characteristics of ocean bottom and hazard type in stratum. Liu Yixuan (1992)⁷ is the first to conduct geological hazard classification on coastal zone of China. Li Peiying (2007)⁸ classified coastal geological hazard into direct type and potential type from the perspective of hazard extent and genetic dynamics, including 6 causes and 60 hazard types. Liu Xiqing (2005)⁹ classified it into 8 series and more than 50 types according to geological hazard action system or status of geological hazard body. Yang Kehong et al. (2010)¹⁰ proposed the major factors of controlling coastal geological hazard of Hainan Province by classifying and studying the geological hazard type of Hainan. By combining previous research results and based on the classification approach of Li Peiying (2007), typical submarine geological hazard of coastal island is classified into 10 types in this paper.

Results

Submarine landslide

Submarine landslide refers to the phenomenon that rock or loose sediment on submarine slope slides down slowly along certain sliding surface induced by gravity¹¹⁻¹³, which mainly occurs in tideway slope area of coastwise Zhujiajian Is., Waidiaoshan Is. and Liuheng Is. in Zhejiang, totally 4 places discovered of obvious submarine landslide. Among them, two places at southwest bank of Zhujiajian Is. are discovered of multistep submarine landslide, and the slide top is located on slope break belt between beach and side slope, with a slope grade of 7.9° and slide length of 500 m. Waidiaoshan Is. has submarine landslide on the northwest slope of coastal island, with a slope grade of 9° and located at the offshore slope break belt where the island spreads seaward, with obvious landslide mass and slide length of about 200 m (Figure 2). Liuheng Is. owns complex submarine topography, ups & downs and deep groove, with a slope grade of above 30° . Obvious landslide mass, surface and two-stage sliding step are discovered on seabed of the above islands, which belongs to monolithic landslide that remains unchanged upon unstability of landslide mass or later movement¹⁴.

Submarine slope

Submarine slope is under the control of coastal landform and mostly developed in places with great topographical change which then become an area with

potential submarine landslide (Figure 2), such as places near water channel and deep groove with high water velocity. Typical ones are Donghai Is., Caofeidian District, Xiushan Is. and Jintang Is.. Among them, Xiushan Is. and Jintang Is. are dominated by underwater slope, the underwater slope grade in the southwest and northwest of Xiushan Is. is about 7° , while a larger slope of 14° exists on the seabed in the north of Jintang Island, Donghai Island and Caofeidian Island are mainly dominated by underwater slope of about $15-25^\circ$. A large number of steep slopes are developed at the entrance between the north of Donghai Is. and Nansan Is. (Figure 3), while the underwater slope of Caofeidian Is. is as long as 15.4 km.

Seabed erosion

Seabed erosion also refers to a kind of potential geological hazard mainly in the form of scouring grooves and pits, with large slope grade causing

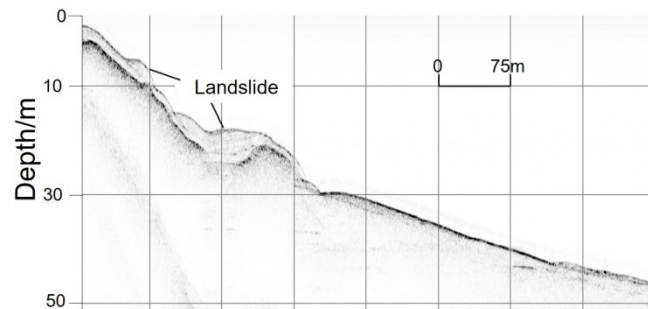


Fig. 2 — Sub-bottom profile map of submarine landslide of Waidiaoshan Is.

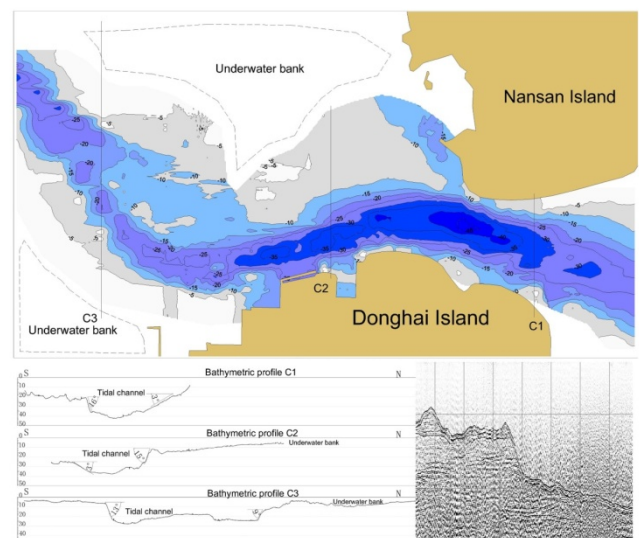


Fig. 3 — Nearshore terrain map and slope sub-bottom profile of Donghai Is.

potential geological hazard. Seabed erosion is discovered in Caofeidian Is., Lingshan Is., Tuoji Is., Zhangzi Is., Beichangshan Is. and Donghai Is. In Caofeidian Is., scouring groove lies in the south in NW-SE strike, with a width of 3.7 km and length of 33.5 km, which is mainly related to geological structure foundation and strong tidal environment of underwater river valley at ancient estuary. In Lingshan Is., tidal scouring groove of 1.50 km long and 0.77 km wide with maximum depth of 40 m, lies in the southeast, which is composed of coarse gravel sediment. In Tuoji Is., it is mainly distributed in the north and south in EW strike. To be specific, it is 1.5 km long, 6.5 km wide and 20-22 m deep in strip distribution in the south, and 0.8 km long, 6.5 km wide and 25 m at the deepest position in the south, with reef exposed. In Zhangzi Is., it lies in the west side of island in SN strike, with groove width expanding from 1 km to 4.5 km from south to north, and bared bedrock at the bottom. In Beichangshan Is., it lies in the west side of the north, and high velocity seriously erodes the seabed to form large sand wave. In Chongming Is., it is developed along the seacoast with a water depth of over 10 m. In Donghai Is., it is developed on underwater slope, underwater bank and tidal channel, with the form slightly different due to their position.

Tidal ridges

Tidal ridge is usually distributed at estuary of nearshore neritic region or strait bottom, in form of linear sand ridges under strong erosion of tide. Tidal ridge is a kind of tide-causative linear sand body with spreading direction consistent with that of tide, which is in parallel arrangement or finger spreading, developed in near shore of Changxing Is. and Lingshan Is. Many large-scale tidal ridges are distributed in western shallow and nearshore area of Changxing Is., basically between 39°30.25'-39°37.75'N and 121°12.1'-121°19'E. These ridges are about 40 m wide and 7 m high at the maximum, striking 120°-300°. Tidal ridge is distributed in nearshore area in the north of Lingshan Is. in strip shape and EW strike (Figure 4), with maximum width of 10 m and length of 200 m.

Moving sandwaves

Moving sandwaves are usually developed on sandy seabed with strong ocean current and also on the surface of some large tidal ridges, such as seabed ridge of Changxing Is., which aggravates ridge

migration and seabed instability. Moving sandwave is widely developed on seabed of Caofeidian Is., Tuoji Is., Dongshan Is., Chongming Is., Changxing Is. and Beichangshan Is. In Caofeidian Is., seabed moving sandwave is mainly distributed in the southwest shoal of fluctuating shelf erosion plain, panland and shoals in shelf eroded depression. In Tuoji Is., sandwave is mainly distributed on seabed near the south scouring groove in strip shape of 5-9 m wide and 1-2 m high. In Dongshan Is., sandwave is widely developed in 6-13 m depth, mainly in continuous large-scale sill-like sandwave with area ranging from $5 \times 10^3 \text{ m}^2$ - $20 \times 10^3 \text{ m}^2$, wavemark in S-N strike, consistent with the shoreline, is intensely developed in sandwave area. Moving sandwave of large single scale is widely distributed in Chongming Is., with maximum wave length of 80 m and height of nearly 2 m. Another typical feature is asymmetrical sandwave profile, namely long and gentle facing the stream surface (west wave surface) while short and steep back to the stream surface (east wave surface), indicating that sandwave tends to migrate from west to east, that is, submarine sediments migrates seaward under the action of runoff (Figure 5).

Shallow gas

Shallow gas refers to a very dangerous potential geological hazard type. Because of high-pressure nature, it can easily lead to blowout, hence causing fire and even burning above oil platform. Strata gas will also reduce the shear strength of the settled layer,

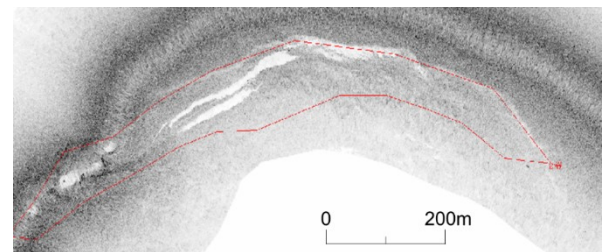


Fig. 4 — Side-scan sonar image of tidal ridge in Lingshan Is.

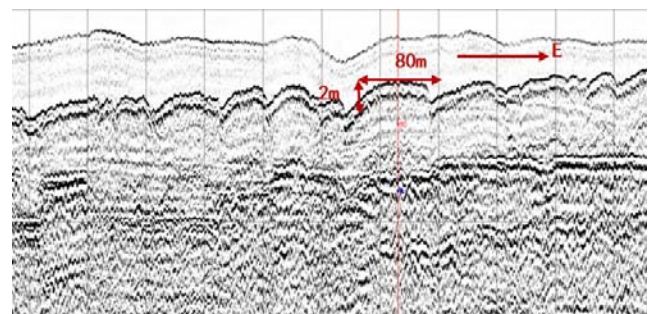


Fig. 5 — Underwater sandwaves of Chongming Is.

compromising the foundation stability of project^{15,16}. Among the islands surveyed this time, shallow gas is found in the seabed of Caofeidian Is. and Liuheng Is. Shallow gas in Caofeidian Is. is mainly distributed in steep underwater accumulation bank slope area in the east, presenting a strip-like distribution, with a length of about 17.6 km and a width of 1-2.3 km. The water area's surface layer in the east of Liuheng Is. covers a typical Holocene shallow marine sediment, about 10-40 m thick. Feature of shallow gas is discovered at about 10 m burial depth.

Wedge-shaped deposits

Wedge-shaped deposit mainly occurs in north side of Beichangshan Is. The typical sedimentary diagonal beddings are presented within the deposits, in angular-unconformable contact with the underlying strata. The inner boundary of wedge-shaped deposits is in parallel distribution with the 30 m isobath on the plane, with highly consistent morphology. It presents an obvious ridge uplift, and the acoustic reflection signals of sediments on both sides of the uplift are obviously different. The changes in local hydrodynamic environment lead to the erosion of original strata, where the external sediments and residual sediments of original strata deposit and fill, thus forming the wedge-shaped deposits. Under the control of hydrodynamic conditions, the submarine sediments in wedge-shaped deposit area will migrate under the action of water flow, causing the change in seabed topography, which poses potential danger of the submarine geological hazard.

Buried oblique layer

Buried oblique layer is mainly developed in the southern seabed of Caofeidian Is. The stratigraphic section is characterized by high-amplitude disordered reflection and filling, unobvious bottom boundary, clear bedding structure of internal filler, structure morphology of mound-shaped protrusions or groove, buried depth ranging tens of meters, and no regularity in distribution. The inclination angle of the buried oblique layer is S-W, which is resulted from sediments of ancient coastal sand dune¹⁷ (Figure 6).

Seabed siltation

Seabed siltation mainly occurs in Donghai Is. The deepwater area at the bottom of tide channel and the underwater bank area at the entrance are locally silted, imposing serious effect on the channel flow. The siltation at the bottom of tidal channel usually occurs in

the deep area greater than 35 m. Moreover, it is surrounded by the protruding topography obviously higher than the surroundings. Further, it forms local relative closed area in the vertical space, where the hydrodynamic conditions are relatively weakened. The sediments migrate along the seabed deposit in the negative relief. It is clear from the data of sub-bottom profile that the formation bedding in the siltation area is obvious, with strong reflection energy. The clay content of deposits is obviously high, indicating the sequence assemblages of deposits formed in different periods (Figure 7). The reflective bedding features of different sedimentary layers show that the sediment trends to migrate from the shoal to tidal channel.

Coral reef degradation

Weizhou Is., the biggest coastal island of the northern gulf, is the main area of coral along the coastal region of South China. Besides, it is located in north margin of endogenous reef coral of the northern gulf, with more than 50 kinds of coral reefs. The coral death of Weizhou Is. is very serious and the situation has not been improved yet. An important indicator of coral resilience - the inadequacy of coral supplementation - suggests that the recovery range of Weizhou coral is limited, with slow recovery rate¹⁸. The death of coral leads to the lessened coverage rate of live coral, affecting the recovery of the coral. The

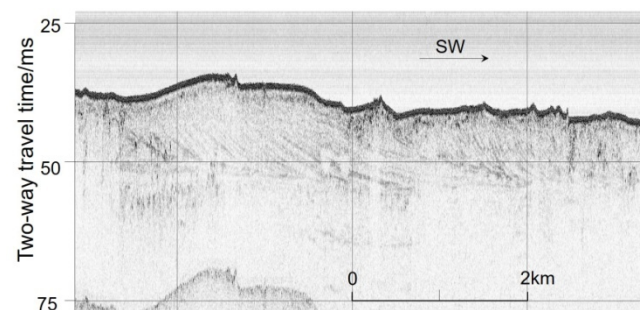


Fig. 6 — Sub-bottom profile of buried oblique layer in the south side of Caofeidian Is.

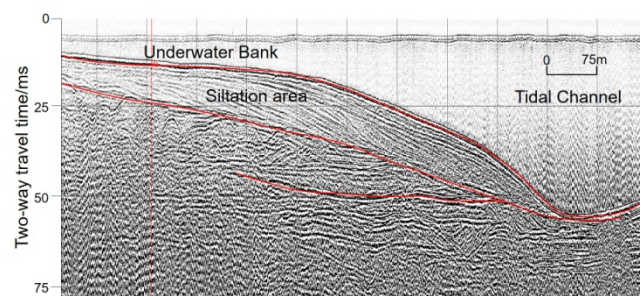


Fig. 7 — Channel siltation of Donghai Is.

high mortality and slow recovery rate of coral in Weizhou Is. indicates that coral is in a degraded and sub-healthy state¹⁹. The coral reef in the east and north sea area of the Weizhou Is. is mainly located in the sea area, ranging from 1.0 to 2.0 km away from the shoreline. In addition, its boundary is in a complex shape. The coral reef tends to be isolated, in the shape of coastal island. The coral reef is filled with sands. Coral reefs in the area are covered with loose sediments, such as sands and coral fragments, and some coral reefs are distributed in the seabed in clumps (Figure 8).

Discussion

Based on analysis of the survey data of submarine geological hazard of islands of different latitudes, types and sizes, distributed in the coastal region of South China, the typical geological hazards of coastal island in China can be classified into 5 main categories: gravity - hydrodynamic force cause, hydrodynamic force cause, pneumatic force cause, biological activity cause and human activity cause (Table 2). Among them, due to the large coastal island area, the number and type of hazards are the most in Caofeidian Island. Located at the entrance of Yangtze River and Qiantang River, where hydrodynamic force is fairly strong and waterway is narrow, seabed

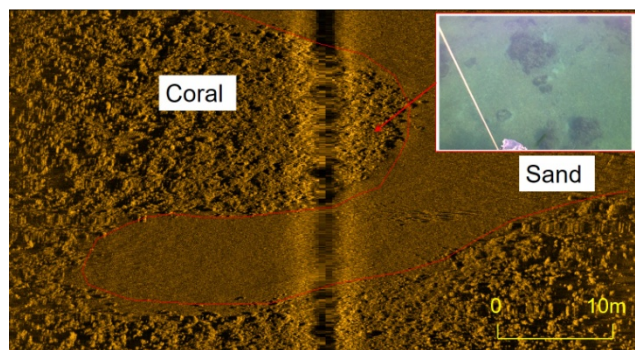


Fig. 8 — Degradation of coral reefs in Weizhou Is.

landslide occurs frequently in Zhoushan Is. The fairly special coral reef in Weizhou Is. keeps degeneration for consecutive years. In other islands, the formation mechanism of submarine geological hazards has their own unique features.

Gravity - hydrodynamic force cause

Submarine geological hazard caused by gravity-hydrodynamic force refers to the geological hazard affected by the hydrodynamic force, mainly owing to the gravity. It mainly includes submarine landslide and slope, while the latter is the dominant factors.

The submarine topography and landform form the major factors controlling the development of submarine landslide and slope. First, as for arc-shaped shore slope controlled by bedrock headland, after the Holocene sea level rises, the original bedrock coast headland forms semi-closed bay. The sand gradually silts and then fills. The arc-shaped shore stretches seaward, deep grooves of headland's outside waterway connect and erode, which causes increasing load of upper slope and gradually steeper slope. Besides, the slope foot erosion forms free surface, thus easily causing landslides. Second, the slopes on both sides of the shoal in tongue-shaped form slow-flow area by the confluence of waterways, with fine granule sands silted in the flow shadow area. The tongue-shaped shoal develops and extends, with both sides close to the deep groove of waterways. The shoal silts and the groove are flushed, which is easy to cause landslide, for example, the western slope of the tongue-shaped shoal of the northern Diaoshan Is.. Third, residual highland slopes exist in the waterway area. There are many residual highlands in Zhoushan waterway area, which have been eroded since the Pleistocene sea water encroaches, but gradually accumulates and widens since the Holocene high sea level. However, the adjacent waterway deep groove keeps flushing, easily leading to landslide¹⁴.

Table 2 — Types and formation mechanism of typical island geological hazards of coastal islands in China

Formation mechanism	Type of hazard	Coastal island
Gravity-hydrodynamic force	Submarine landslide and slope	Zhujiajian Is., Waidiaoshan Is., Liuheng Is., Donghai Is., Caofeidian Is., Xiushan Is. and Jintang Is.
Hydrodynamic force	Seabed erosion, Tidal ridges, Sandwaves, Wedge-shaped deposits, Buried oblique layer and Seabed siltation	Caofeidian Is., Lingshan Is., Tuoji Is., Beichangshan Is., Donghai Is., Changxing Is., Dongshan Is. and Chongming Is.
Pneumatic force	Shallow gas	Caofeidian Is., Liuheng Is.
Biological activity	Coral reef degradation	Weizhou Is.
Human activity	Submarine landslide, Slope, Coral reef degradation...	Donghai Is., Zhujiajian Is....

Sea storm and internal waves impact the stability of the submarine slope. Waves lead to circulating pressure of seabed in the process of transmission, which triggers the turning force moment and increases the shear stress of the seabed. If the soil strength is unable to resist the increased shear pressure, the seabed will be destroyed. The waves transmit along the surface of the seabed, which can arouse the excess pore pressure, including the instant pore pressure and accumulated pore pressure. In addition, it can weaken the effective strength of the soil, so as to increase the instability of the slope. When the seabed soil is completely liquefied, the sediment can slump along the slope surface²⁰.

Tiding impacts the stability of submarine slope. Three causes of landslides resulting from tidal fluctuation: first, the seabed in the estuary consists of fine-grained soil with poor permeability, and the load on the sediments fluctuates with local variation of tidal range, and then the load change increases the pressure of pore water. Second, the water permeates into the sea when tides fall, and the seepage force impacts the stability of slope. Third, the increase of effective overlying pressure on the soil results in soil compression and decline when tides fall, and the landslide will occur when the resistance is less than the sliding force.

Hydrodynamic force cause

The submarine geological hazards caused by hydrodynamic force include seabed erosion, tidal ridges, sandwaves, wedge-shaped deposits, buried oblique layers and seabed siltation. The dynamic effect of currents or wave motions in the scouring grooves and pits and other similar landforms shaped by seabed erosion is very strong. The erosion with mass movement of sediments often forms the landforms where the submarine topographic relief is obvious and the sediments in the groove are unstable. Tidal ridges are the deposits at high speed, and their sediments hold a large number of seawater, poor consolidation degree, strong compressibility, low bearing capacity and unstable submarine soil. Sandwaves and wedge-shaped deposits can cause more serious damage due to the continuous movement of sand. The inter-bedding sliding and local collapse are prone to happening in the high-angle cross bedding, such as buried ancient watercourses, sand dunes and so on. The gravel is the main sediments with strong permeability, and the local collapse is prone to happening due to long-term erosion, scouring

and overlying load, destroying the original stratum structure. Seabed siltation is a deposition process in the harbor basins and channels formed by hand excavation, where the original hydrodynamic equilibrium is changed by human activities.

The seabed is prone to being scoured under the strong hydrodynamic force because the coastal island is isolated and it is directly influenced by tidal waves. For example, the seabed erosion in the Chang-shan Archipelago and the Miaodao Archipelago in the Bohai Sea can be seen here and there. Scouring grooves mainly lie in the coastal and continental shelf, with the depth of about 10-30 m, especially in the tidal channel groove between the islands. The scouring groove is not stable, and the cyclical strong and weak replacements of tidal currents change the shape and depth of grooves, the grooves also moving in the horizontal direction. The tidal ridges are the sandy ridge deposits with fast migration, mainly formed in the tidal current area of reciprocating flow, where the sand is abundant, and the tidal current velocity in the hydrodynamic force is 2-3 kn. The sandwaves are the regular wavy undulating landform with loose sandy deposits on the submarine surface. With the action of waves and currents, the sand is unstable at the bottom of scouring grooves or on the sand ridges, and intensive scouring, deposit and sand mass movement in the submarine are followed by sandwaves movement. At the same time, the deposit is prone to appearing in the deep water areas and on the condition acted on weak hydrodynamic force, such as the inner channel of Zhanjiang Bay in the Donghai Island. In addition, changes in hydrodynamic conditions caused by sea level movements also have a long-term impact on the stability of submarine geological hazards. During the Quaternary glaciation, the decline of the sea level formed a large number of watercourses and lakes in the continental shelf. However, the early watercourses have plunged into the seabed since the Holocene sea level rose sharply, and most of them are buried under the sediment layer with different thicknesses, forming high-angle oblique layer areas such as sediment layers of buried ancient watercourses, sand ridges and sand dunes. Such geological hazards are more common in the Caofeidian Island. Therefore, submarine geological hazards caused by hydrodynamic force are more common.

Pneumatic force cause

The submarine geological hazards caused by pneumatic force mainly refers to the geological hazards caused by submarine shallow gas. Submarine

shallow gas is defined as the organic gas accumulating at a shallow depth of 1,000 m below the seabed, lying in the estuary and continental shelf, including the Chinese large estuaries and continental shelves. For example, a large area of shallow gas formed by biological debris lies in the Liaodong Bay, the shallow seas in Shandong Peninsula, the Yangtze River Estuary, Hangzhou Bay, the offshore areas of Zhejiang Province, the Pearl River Estuary, Beibu Gulf, the offshore areas of Southeast Hainan, the pro-delta facies and delta-front facies of submarine delta of the Yellow River, the submarine delta of the Yangtze River. Besides, the shallow and thermogenic airbag and air mass lie in the oil and gas resource area in the continental shelves of the East Sea, the Yellow Sea and the South Sea of China due to fracture control, in the depth of hundreds of meters in the stratum²¹. In the geological hazard investigation of coastal island, the sign of shallow gas was found in the seabed of Caofeidian Island and Liuheng Island.

Shallow gas includes some methane decomposed by organic materials in submarine sediments, and some other gas migrating from deep stratum to shallow stratum, with three main existence forms which are gas-bearing sediments, saccular lenticles, and layers. Under the action of the pressure of overlying water layer, soil layer and rock stratum, the shallow gas is always migrating and aggregating once it is generated, and the pressure action is important to the shallow gas migration. In low permeability sediments (such as clay and silty clay), the shallow gas generally migrates upwardly in the vertical direction, in highly permeable sandy sediments or cracking rock stratum, the shallow gas migrates along the stratum in the updip direction. The shallow gas threatens the safety of submarine structures definitely, and it will cause immeasurable economic loss in the event of any hazard.

Biological activity cause

The submarine geological hazards caused by biological activities mainly refers to the coral reef degradation, and it refers to coral reef degradation of the Weizhou Island. It is widely accepted that the coral reef degradation is speeding up globally, and the causes of common speculation are global changes, eutrophication in coastal waters and the reduction of herbivorous fish, often cited as the major cause of coral reef degradation^{22,23}. The major cause of coral reef degradation is the increase of death rate caused by global extreme weather, regional climate change,

destructive human activities and so on through the study on the evolutionary process of coral reef diversity in the Weizhou Island.

The ecological survey on coral reefs in the Weizhou Island, conducted by Huang Hui *et al.* in July 2005²⁴ showed that the distribution area of hermatypic corals in the Weizhou Island and the coverage of live corals decreased dramatically. At present, the average coverage is just 23.8 % in the southern and northern ports in the Weizhou Island which was covered by fine and massive corals in the past, while that of dead hermatypic corals was 31.4 %. The biodiversity of hermatypic corals are very low, and each dominant species with a dominance of over 60 %. The coral reefs were still covered by much sand, and it wasn't optimistic for coral reefs' recovery from a survey in 2012. These findings show the great changes of marine environment in the Weizhou Island, and the coral reefs have been degrading dramatically.

Human activity cause

With rapid economic development in modern era, there is a growing number of human activities including development and utilization of coastal island and submarine areas. Wharf construction, channel dredging, seasand mining, environment pollution and excessive exploitation have changed not only original landforms, but also hydrodynamic equilibrium, causing very serious geological hazards. Human activities are involved in the causes of geological hazards mentioned above more or less. For example, steep slopes caused by the construction of seawall in the Waidiaoshan Island, wharf in the Caofeidian Island and excavation of harbor basin in the Donghai Island have further increased the possibility of submarine landslides. Besides, lack of resources by sand mining in the offshore and seabed has worsened seabed scouring, and the destruction of hydrodynamic conditions has accelerated the channel siltation, coral reefs been devastatingly destroyed by environmental pollution, disorderly exploitation and over-fishing. Therefore, human activities play a more and more vital role in the causes of geological hazards.

Conclusion

The causes of typical geological hazards in the coastal island and submarine areas in China are mainly classified as five: gravity-hydrodynamic force cause, hydrodynamic force cause, pneumatic force cause,

biological activity cause and human activity cause, including 10 types: submarine landslide, submarine slope, seabed erosion, tidal ridges, sandwaves, shallow gas, wedge-shaped deposits, buried oblique layers, seabed siltation and coral reef degradation.

The hydrodynamic force cause accounts for the largest proportion in the causes of submarine geological hazards, and seabed erosion is the most developed. This can be explained by the marine environment in which the tidal currents flow with a large flow velocity, strong wave action and especially intensively hydrodynamic force around the coastal islands, especially in the narrow waterways.

The geological hazards caused by human activities are more common. All kinds of submarine geological hazards are involved in the impact of human activities. Disorderly unplanned and under-regulated development activities of coastal islands undermine the original submarine landform and hydrodynamic equilibrium, resulting in a series of serious geological hazards, especially the serious impact on coral bio community which is very sensitive to the marine environment.

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